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Contribution to the study of the impact of sulphates, temperature and humidity on the behaviour of Compressed Stabilized Earth Blocks CSEB

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ABSTRACT

The use of Compressed Stabilized Earth Blocks CSEB as a masonry unit is still growing in many countries because of their low impact on the environment. However, in addition to being sensitive to weather variations like humidity and temperature, earthen constructions are subjected to chemical agents such as sulphates. This work deals with the assessment of the impact of sulphates combined with temperature and humidity on the behaviour of CSEB in terms of compressive strength and mass loss. Earth blocks have been stabilized with different amounts of two types of cement, namely: CEM II, and CEM I resistant to sulphates. The compressive strengths under humid and tempered conditions were first measured. Physical properties involving shrinkage and thermal conductivity, which are depending on humidity and temperature, were measured based on cement amount variation. A correlation between these two parameters and the compressive strength was discussed. The impact of sulphates combined with humidity and temperature was then investigated. The results show that contrary to humidity, temperature increases the compressive strength as much as the cement amounts rise. Cement dosage favours the thermal conductivity, and opposes the shrinkage. The CEM II is particularly more efficient than the CEM I under the effect of temperature. On the other hand, the compressive strength is weakened in the presence of sulphates. However, the use of CEM I resistant to sulphates at high percentage can make the blocks withstanding the action of sulphates. The mass of CSEB is modified after the exposure to sulphates, humidity and temperature. Sulphates fill the air pores under the effect of temperature through crystallization of products issued from their reactions with cement. This leads to less material losses contrary to water exposure that causes leaching of soluble products.

Keywords: CSEB; CEM I; CEM II; humidity; temperature; sulphates

Introduction

Compressed Stabilized Earth Blocks CSEB are a traditional material that involves compacting in moulds raw earth in which are incorporated stabilizing binders of different nature in order to improve the mechanical properties and the durability. CSEB are considered as the most used among the earth building techniques. The control of temperature and relative humidity is the main advantages in using CSEB; this property improves the living comfort. The possibility of using nearby soil resources allows their accessibility to middle-class people, who aspire increasingly to this economic material, which meets in addition the concept of the sustainable development and minimizes the carbon footprint [1]. The drawback in using CSEB consists in their susceptibility to alternate environmental factors such as driving rains and insolation. According to Saidi et al. [2], the performance of this material is mainly depending on its hygrothermal behavior.

Many other researchers [3-7] considered the problem of CSEB sustainability to adverse weather conditions as a serious preoccupation. However, very little formal research considered the behavior of CSEB towards chemical attacks. In the field of building materials, sulphates remain the greatest concern because of their frequent occurrence in nature, and their deleterious effects on cementitious-based materials. Sulphates are generally present in marine waters, subterranean or industrial waters [8], in the air in a gaseous form, and particularly in soils, usually identified as mentioned by Wild et al. [9] as saline efflorescence. These minerals are likely to react with cementitious binders and may under certain conditions compromise the behavior of the materials.

It is proposed in this study to carry out an investigation on CSEB made of a coarse soil treated by physico-chemical stabilization based on two types of cement: a CEM II, and a CEM I resistant to sulphates. Initially, compression tests have been performed on natural blocks as well as on saturated and oven dried blocks to assess the mechanical performance varying the cement amount under hygrothermal conditions. Measurements of drying shrinkage and thermal conductivity were achieved to point up the correlation between the strength development, the dimensional variation, and the heat transfer. The impact of sulphates coupled with humidity and temperature was then analysed after curing cycles involving the three parameters. Indicators of eventual damages involved compression tests and mass loss measurements.

Material and Methodology

Materials

Soil

A local soil was provided from the region of Thénia (Algeria). Identification tests were carried out to characterize the soil engineering properties, and to check its suitability for the stabilization according to the criteria defined in the literature as reported by Houben & Guillaud [10] and others. Suitability criteria are related to the grain size distribution,

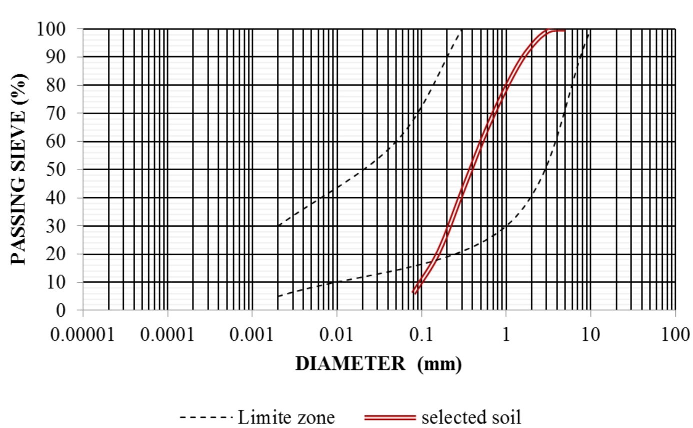

Figure 1. Grain size curves of the studied soils compared to the limit zone.

the consistency, and the Proctor properties. Figure 1 gives the soil particle size distribution curve compared to the lower and upper limits. The main engineering characteristics and the chemical analysis are given respectively on Tables 1 and 2.

The engineering characteristics allow identifying a sandy soil suitable for the stabilization process. The amounts of chemical elements that could be deleterious are beyond the levels classified of high risk [10].

Table 1. Soil engineering properties

Proportion %	Selected soil
Fine Sand 0.02 – 0.2 mm	27
Coarse Sand 0.2 – 2 mm	67,08
Gravel > 2 mm	5,92
Proctor optimal water content %	12
Dry density (g/cm^3)	1.75

Table 2. Chemical composition of the soil used

CaO%	Al_2O_3%	SiO_2%	MgO%	Fe_2O_3%	K_2O%	Lost on ignition	4.45%
3.09	16.9	62	2.43	4.98	3.5		
Na_2O%	MnO_2%	TiO_2%	Cl%	SO_3%	P_2O_5%		
2.97	0.10	0.53	0.086	0,015	0.17		

Stabilization binders

As defined by Mahdad et al. [11], the stabilization refers to any physical, chemical, biological, or combined method of alteration of soils which aims to improve their properties. The soil used in the present study was treated with cement as this latter is known to be more effective with coarse soils. In addition, cement stabilization has gained popularity due to faster strength gain [1]. Two types of cement produced by Lafarge Algeria in accordance with

Table 3. Chemical composition of both types of cement

Chemical analysis	CEM I	CEM II
CaO %	61.8	58.2
Al_2O_3%	3.94	4.28
SiO_2%	21.8	17.6
MgO %	1.78	1.78
Fe_2O_3%	4.61	2.91
K_2O%	0.54	0.63
Na_2O%	0.092	0.088
MnO_2%	0.1	0.049
TiO_2%	0.22	0.22
Cl%	---	---
SO_3%	2.08	2.8
P_2O_5%	0.2	0.13
Lost on ignition	3.72	10.53

EN197-1were separately used: a cement CPA-CEM I 42.5-ES, NA 443 (sulphates resistant with C3A% = 5%), and a cement CPJ-CEM II/B-42.5N, NA 442. The chemical characteristics of both types of cement are given in Table 3.

Methods

Blocks preparation

The following laboratory procedure was adopted for the blocks preparation: The soil was oven dried at 105°C during 24 h to remove all initial water content. A 5 mm sieve was then used to remove any pebbles before incorporating the binders. These were properly added as percentage of the dry soil weight in proportions of 4, 6, 8 and 10%. Over 10%, the stabilization process would not be economic [12,11]. According to González-López et al. [13], the quantity and type of addition is depending on the characteristics of the soil type and on the expected performance of the CSEB.

Water was then gradually added until the suitable consistency was achieved. This was obtained at a water amount of 10% of the materials dry weight. This value was adopted after several experiments of water quantities regardless the Proctor Optimum Water Content value, as this one was found to be unsatisfactory. Some authors such as Izemmouren et al. [14] have also considered this value as non-suitable for CSEB since the energy supplied in a Proctor test is different from that supplied in the static compaction process used during the manufacture of CSEB.

After that, the blocks were moulded by compacting quantities of the stabilized soil mixed to the selected water content, and introduced in parallelepiped moulds (Figure 2). A press that produces a compaction pressure of approximately 7,5 MPa was used to make blocks of 295×85×140 mm3.

Figure 2. (A,B) mixing and moulding of CSEB.

Curing

Right after compaction, the fresh demoulded blocks were damp cured to avoid a premature drying and to allow to the hydration reactions to occur. The curing process consisted of a daily light watering for a week with a wrap under a plastic canvas during the first 14 days (Figure 3). The blocks were then let drying at ambient laboratory temperature until their characterization.

Figure 3. (A,B) CSEB curing.

CSEB Characterization

Compressive strength under humid and tempered conditions:

The compressive strength gives an idea on the load-bearing performance of CSEB; lower compressive strength means that earth blocks can only be used for self-bearing members and the number of building storeys is limited [15].

Considering environmental changes like humidity and temperature during the lifetime of CSEB is thoughtful as the material properties are expected to be altered under such variations.

Measurements of the CSEB compressive strengths varying amounts of both types of cement were performed after 28 days to assess the mechanical performance (Figure 4). The tests were carried out on natural blocks, on saturated blocks after 24 h of water immersion, and on dried blocks after 48 h of oven drying at 40°C. A minimum of three tests was conducted for each cement dosage. The first compressive strengths nomenclature is listed in Table 4.

Figure 4. CSEB compression test.

Table 4. First nomenclature of CSEB compressive strengths

Compressive strength	Blocks
R_0	Natural block at initial state
R_H	Saturated block (24 h of soaking)
R_D	Oven dried block (48 h of oven drying)

Thermal conductivity

The thermal conductivity (λ) is one of the most studied thermo-physical properties in building materials. The estimation of this thermal characteristic is necessary to evaluate the energy consumption in building [2], particularly in a dry climate [16]. In the field of constructions insulation, this property has to be minimised.

Requirements regarding the thermal insulation and the strength are generally opposed to each other when it comes to earthen blocks walls, since in one hand the thermal insulation is enhanced with the porosity, while strength is great as much as the density is high. This was already stated by Adam & Jones [17].

As temperature affects the mechanical performance, the thermal conductivity was measured to indicate the relation between the heat transfer and the strength evolution according to the cement amount. In the current study, the blocks were oven dried to constant mass before measuring the (λ) value in order to avoid the influence of the humidity content; the thermal conductivity is very sensitive to water content [10]. The measuring device consisted of a CT mètre connected to a probe containing a resistive wire between two samples (hot wire probe). These latter were subjected to a heat flow. The evolution of temperature measured over time with a thermocouple contained within the probe allowed to determine the thermal conductivity (Figure 5).

Figure 5. Thermal conductivity measurement.

Shrinkage

Under the effect of temperature, CSEB can undergo contraction due to the evaporation of the free humidity. This is likely to lead to both temporary and permanent modifications in the physical and chemical properties of the block [18]. The mechanical properties can also be affected due to the expected dimensional changes as well as to the eventual cracks. These are depending on the water amount, the porosity, and the cement amount.

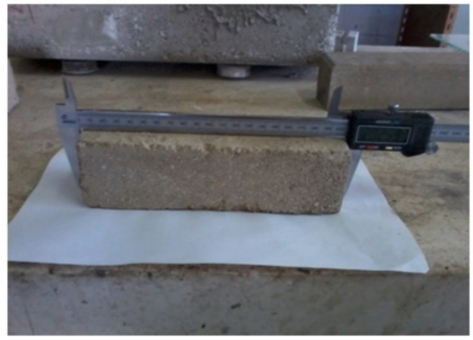

Figure 6. Drying shrinkage measurement.

The degree of shrinkage (Figure 6) was assessed following the methodology described in the South African National Standards SANS 1215 [19], which consists in immersing samples of dimensions 200 x 60 x 60 mm3 in a water bath for 96 h at a temperature ranging from 16°C and 18°C. A first measurement (A) is done with a Vernier gauge of 0,01 mm precision. After that, the samples are oven dried at a temperature between 69°C and 71°C for 48 h. A second measurement (B) is done. The drying shrinkage is then calculated according to Eq. (1)

$$\text{Drying shrinkage} = (A-B)/B \times 100 \tag{1}$$

where :

A = saturated length.

B = dry length.

Impact of sulphates combined with humidity and temperature

Sulphate attack is considered as one of the most aggressive environmental deteriorations of cementituous materials. In order to analyze the impact of sulphates on CSEB when combined with humidity and temperature, blocks were subjected to immersion methods including wet-dry cycles. The methodology applied consisted of 12 cycles of full immersion/drying. Each cycle was performed in three phases: a wet phase achieved with a sulphate solution for 5 hours, an oven-dry phase at 71°C for 42 hours, and a cool phase in open air for 1 hour. A control solution based on neutral water (empty sulphate solution) was used in parallel for comparison. This methodology was adopted from the ASTM D559 Water Durability Test. The sulphate solution was prepared with 5% of $(NH_4)_2SO_4$. This type of sulphate was chosen because of its frequent use in soil fertilization of agricultural lands, which promotes the release of sulphates in nature. The amount of 5% was adopted as an extreme dosage based on

Table 5. Nomenclature of CSEB compressive strengths after the aging tests

Compressive strength	Blocks
R_S	After cycles involving sulphates
R_W	After cycles involving neutral water

concrete literature as well as on stabilized soil literature, where levels of risk according to sulphates amount values have been defined [9,20]. The behavior was rated through compressive strength tests as well as weight loss measurements after the ageing trials (Figure 7). The compressive strengths nomenclature after the combined tests is noted in Table 5.

Figure 7. Sulphates and water test.

Result and Discussions

Compressive strength vs. cement content

First results of compressive strength for initial blocks, humid blocks and oven dried blocks are given in Figures 8 and 9, respectively according to CEM I and CEM II dosages.

The figures show that the blocks strengths increase proportionally to the cement amount for both types of cement regardless the conservation condition. Initial strengths values range from 4,8MPa to 7,7MPa and from 4,3MPa to 8,3MPa respectively when CEM I and CEM II amounts rise from 4% to 10%. Recommendations for common CSEB in some guidelines for structural applications suggest a minimum dry strength requirement of 6MPa [21,22]. The blocks stabilized at 8% and 10% are fulfilling the requirement, whilst those at 4% and 6% proved unsatisfactory. Regarding the humid strengths, values are lower than the initial values. Between the two cements, no significant difference is observed. Furthermore, the blocks at 4% do not meet the minimum humid requirement which is 3MPa. However, after oven drying, there is a significant increase in the strengths with both types of cement, particularly with the CEM II. This latter proves more efficient under the effect of temperature compared to the CEM I.

Cement stabilization imparts strength to CSEB. As explained by Mahdad et al. [11], the cement particles are dissolved in mixing water and soil. The released ions in the dissolution process reach a critical concentration, and then precipitate out of the solution to form a cement film that envelops the soil grains. This provides resistance to the stabilized blocks.

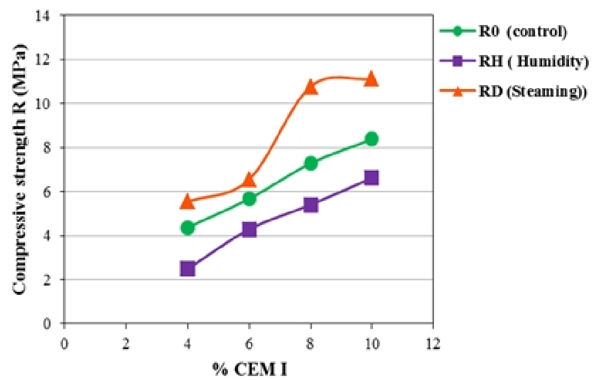

Figure 8. Compressive strengths of CSEB function of CEM I content.

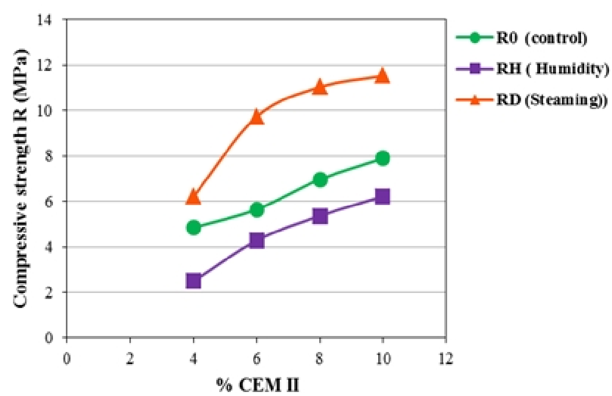

Figure 9. Compressive strengths of CSEB function of CEM II content.

Regardless the type of cement, the CSEB behaviour under the different conservation conditions is analysed hereafter. The blocks exhibit good strength under the effect of temperature due to the acceleration of hydration reactions and binders setting. In the hydration stage, anhydrous components of cement and water react with the soil minerals to produce hydrates (hydrated calcium silicates C-SH and hydrated calcium aluminates C-A-H) which crystallize with temperature. This phenomenon is known to occur in cementitious based materials as the formation of hydrates depends on the dissolution of minerals, which is favoured by temperature [14]. Several researches [23,24] have already shown that higher temperatures accelerated the chemical reactions and the soil strength development.

Considering the action of both types of cement, the CEM II tended to be more efficient under the temperature effect. This might be due to the supplementary cementing materials contained in the CEM II which have a pozzolanic effect, unlike the CEM I that is known to have slower hardening.

On the other hand, the decline in strength after total immersion is due to the pressure generated on humidity exposure which softened the bonds between particles, and dissolved the calcium hydroxide contained in the hardened cement matrix. The dissolution process is not reversible and causes leaching of unstable particles. This is more noticeable at low cement content (4%). The lower the cement content is, the higher the strength losses are.

Thermal conductivity vs. cement content

The CSEB thermal conductivity variation is illustrated in Figure 10 according to both types of cement. With the CEM II variation, the curve indicates an increased thermal conductivity with the increase of cement amount; while with the CEM I, the heat transfer almost stabilizes after 6%.

The blocks density is generally enhanced with the cement pores filling. Between both types of cement, the results reveal a better efficiency of the CEM II at providing density and then at favouring the thermal transfer. This is in accordance with the previous results with regard to the compressive strengths after the oven drying process. The CEM II proved more efficient under the effect of temperature compared to the CEM I.

Regarding the cement filling action, the thermal conductivity increased due to the reduction of air volume whose conductivity is relatively weak. Increasing cement content increases the hydration products that fill the spaces between soil particles [2]. According to Ben Mansour et al. [25], at dry state and at low water contents, the heat transfer is done primarily at the points of contact between grains forming the material. The mixture becomes more homogeneous with the cement addition [16], which translates in to increased thermal conductivity.

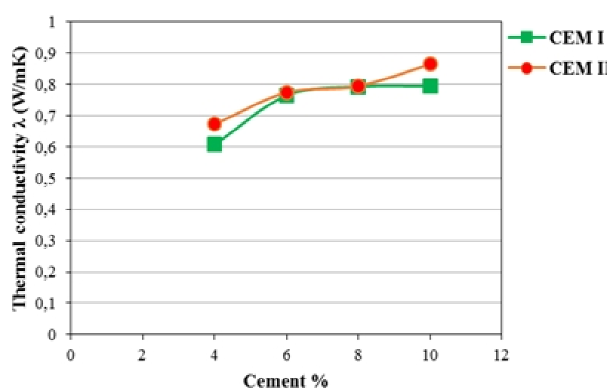

Figure. 10. Thermal conductivity variation of CSEB function of cement content.

Shrinkage vs. cement content

Figure 11 outlines the evolution of the CSEB shrinkage function of cement content.

The general trend of the shrinkage converges towards a diminution with the cement amount increase. Both types of cement proved effective at controlling the shrinkage. By comparing the two types of cement, the shrinkage decreases significantly by more than 40% between 4% and 6% CEM I. The decrease rate is then lower over 6% CEM I. The minimum shrinkage value at 10% CEM I approaches 0,1%. With the CEM II, the shrinkage is well countered between 4% and 6% since it decreases by more than 30%, but it almost does not vary beyond 6% CEM II where values are near 0,15%. Walker [12] observed decreasing values of shrinkage with cement amount addition. Commonly used shrinkage limits mentioned by the same author were between 0.08% and 0.10%. In the present study, 6% of both types of cement were an optimum amount performing in limiting the shrinkage.

It can be said that under the effect of temperature, the stabilizing action of cement is reflected in enhancing the compressive strength and in opposing the dimensional variations undergone by CSEB, even though for cementitious materials, high amounts of cement would likely generate greater shrinkage. After the expulsion of water contained in pores, the remained water that is adsorbed on cement gel is progressively driven out over long-term. The process is known to be slow and irreversible.

Impact of sulphates combined with humidity and temperature

After the tests involving sulphates and neutral water, some defects were observed including surface scaling and corners chipping. A crystalline tough texture and some efflorescence were in addition observed on the blocks exposed to sulphates (Figure 12). The compressive strengths as well as the mass losses were measured.

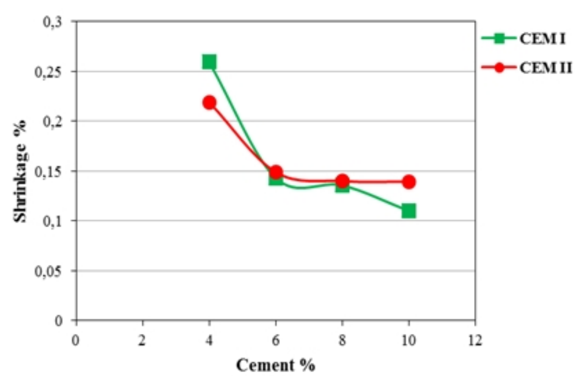

Figure 11. Shrinkage evolution of CSEB function of cement content.

Figure 12. CSEB after water and sulphates exposure.

Compressive strength

Regarding the mechanical behaviour, Figures 13 and 14 depict respectively the compressive strength evolution of CSEB according to the cement amounts. The initial strengths R0 are also shown up for comparison.

The CSEB withstood the cycles of combined water and temperature without any decline in the mechanical properties. The compressive strength increased as much as the cement amounts rose. The rate of increase compared

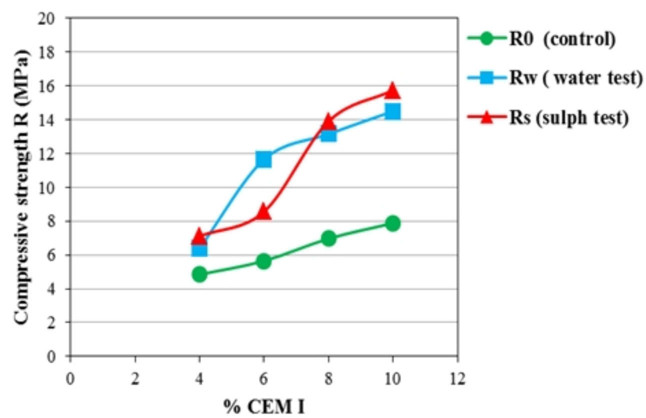

Figure 13. Compressive strengths of CSEB after sulphates and water tests function of CEM I content.

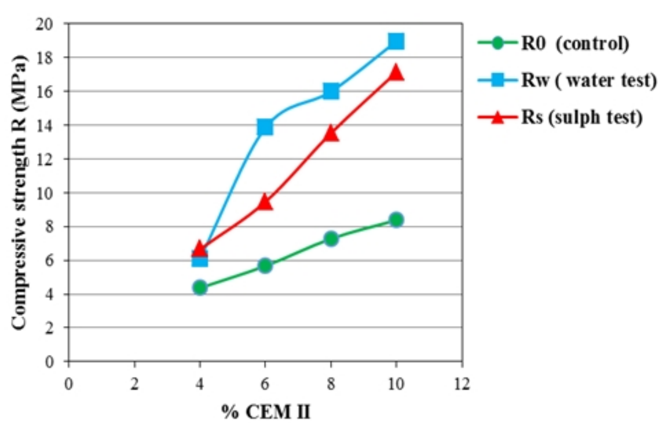

Figure 14. Compressive strengths of CSEB after sulphates and water tests function of CEM II content.

to control specimens is more important for CEM II blocks compared to those incorporating CEM I. The strengths differentials exceed 100% at high CEM II amounts (6%, 8% and 10%).

The strength values recorded after the test involving sulphates are lower than those recorded after the water test for both types of cement except at 4%, where both strengths are nearly equal, and at 8% and 10% CEM I, where the strengths exceed somewhat those recorded after the water test.

By comparing both conservation conditions, the CEM II stabilized blocks exposed to sulphates showed weak mechanical performance compared to those subjected to neutral water, whereas the CEM I stabilized blocks exhibited different behaviour compared to that of CEM II blocks. After the water test, the strengths increased to a less extent compared to the specimens incorporating the CEM II. Furthermore, sulphates did not have a significant effect on the compressive strength at high amounts of CEM I (8% and 10%); instead, the strengths exceeded those obtained after the water test.

The impact of sulphates and humidity combined with temperature is examined as follows: The blocks achieved the cyclic test involving neutral water and temperature without suffering deleterious effects due to cement hydration reactions that were favored and accelerated in alternated subjection to humidity and temperature, even though expectation would have to be converging on a weakening of the mechanical properties under such conditions. The compressive strengths developed once the formed hydrates were fixed on the soil particles and crystallized as much as the temperature rose. In a quasi-similar experience performed by Goual et al. [26], the author noted on soil specimen stabilized with cement, and conserved during 7 days into water that the compressive strength increased with the immersion duration. The effect of temperature was elsewhere proved to contribute to the improvement of the compressive strength [23, 24, 14]. The blocks particularly stabilized with CEM II reached the highest strengths because of the supplementary cementing materials contained in this cement.

However, the cyclic test involving sulphates induced different behavior due to the increased sensitivity of CSEB in the presence of sulphates. The formation of adverse products namely gypsum and sometimes ettringite in air voids as explained in Eqs. (2), (3), (4) exerts stresses after crystallization and germination in the confined pores, and leads to a loss of integrity over time. Gypsum softens the cement matrix and makes the blocks more vulnerable, whereas ettringite causes swelling and increases the porosity by forcing particles to separate [27]. The Gypsum formed from the reaction between Portlandite and sulphates (eq.2) is known to lack some basic properties such as stability in water. This product is not durable in case of saturated media due to its solubility in water [7], but in solid state and at high temperatures, its crystalline character confers some solidity. The alternate exposure to humidity and temperature made the stabilized blocks more likely to exhibit sensitivity to sulphates, but at different extent depending on the type of cement and on the amount of addition: The CEM II performed with less effectiveness towards sulphates, unlike the CEM I which was more efficient at high amounts (8 and 10%), and proved effective at controlling the impact of sulphates intrusion. The CSEB with high amounts of CEM I did not suffer from the compound effect of sulfate attack and dry-wet exposure than that stabilized with the CEM II whose blocks showed weak performance compared to the same blocks exposed to neutral water. Generally, cements of class CEM I are designed with low tricalcium aluminate (C3A) content to limit reactions inducing sulphate attack.

$$Ca(OH)_2 + (NH_4)_2SO_4 \rightarrow CaSO_4.2H_2O + 2NH_3 \text{ gypsum} \tag{2}$$

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2(OH)^- \text{ Ionisation of calcium hydroxyde} \tag{3}$$

$$6Ca^{2+} + 2Al(OH)_4^- + 4(OH)^- + 3(SO_4)^{2-} + 26\ H_2O \rightarrow Ca_6[Al(OH)_6]_2 . (SO_4)_3. 26\ H_2O \text{ ettringite} \tag{4}$$

Mass loss

Surface deterioration took place through scaling phenomenon which led to some material losses. The severity of the scaling depended on the conservation environment, on the type of cement, as well as on the stabilization amount. The results of mass loss were recorded and depicted in Figures 15 and 16 respectively for CEM I and CEM II variation.

The results show that generally the mass loss is greater at the lower cement dosage. The permissible limits of mass loss for CSEB are defined according to ASTM Standards as 5% in rainy areas and as 10% in dry areas.

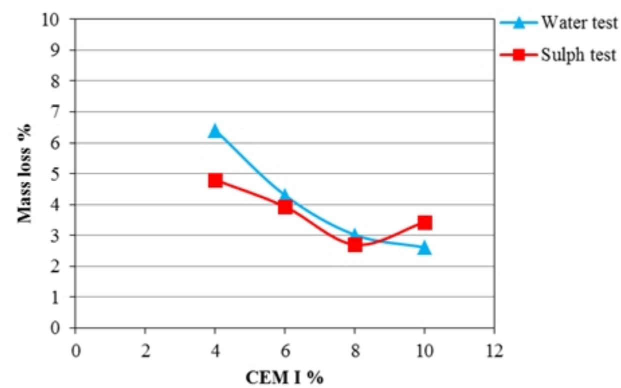

Figure 15. Mass loss of CSEB after sulphates and water tests function of CEM I content.

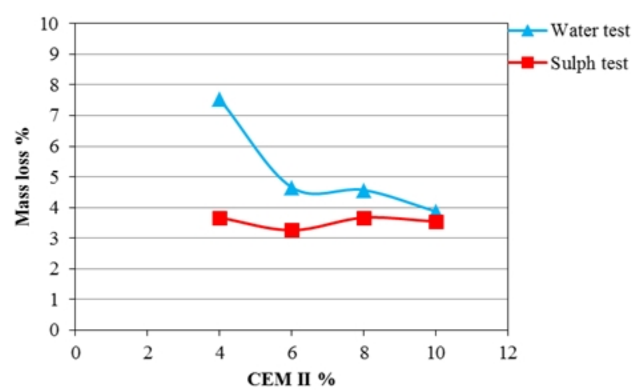

Figure16. Mass loss of CSEB after sulphates and water tests function of CEM II content.

According to that limits, the blocks at 4% are the most vulnerable. For higher amounts of cement, the results compare favorably with the maximum permissible.

By comparing both conservation conditions, the mass loss obtained after the water test are higher than those recorded after the sulphates test, especially for CEM II specimens. However, there is an exception at 10% CEM I, where the mass loss after the water test is somewhat less than that after the sulphates test.

It was noted that during the tests, the mass of the blocks fluctuated in a non-uniform way between increase and decrease. The cyclic changes in ambient conditions have ultimately induced cracks, which subjected the surface of the blocks to an easy entry of moisture as well as sulphates. The mass variation trend suggested that the progressive absorption of both solutions (water and sulphates) followed by temperature exposure involved the formation of reaction products, which induced a mass gain. Thereafter, the dissolution of the binder matrix and the elimination of those reaction products due to leaching after the re-exposure to humidity led to a mass decrease, but as previously mentioned according to the type and amount of cement.

Furthermore, the reason for the low global material loss after exposure to sulphates compared to the exposure to neutral water is the precipitation of gypsum in the blocks cavities. The physical filling of gypsum crystals and eventually of ettringite induced a low mass loss, unlike the neutral water which likely detached particles and induced dissolution of some calcium hydroxide. The effects of sulphate reactions were then more noticeable at weakening the compressive strength rather than at causing material loss.

Conclusions

This work sought to assess through experiments the impact of sulphates, humidity and temperature on the behaviour of CSEB treated with two types of cement. The blocks were first characterized under humid and temperature conditions. The action of sulphates combined with humidity and temperature was then investigated. The main conclusions derived from the investigation are summarized as follows:

The oven-curing is always beneficial for CSEB. Its adoption for practical purposes is highly recommended when accelerated performance is required. However, the action of moisture depends on the degree of stability of the reaction products issued from binders' hydration and from soil minerals dissolution. Both humid and dry strengths are nevertheless an increased function of cement amounts. The CEM II is more efficient under the effect of temperature.

The thermal conductivity increases with the cement addition. The heat transfer is particularly favoured with the CEM II. This explains the improved strength performance of the CSEB incorporating the CEM II when cured with temperature.

The dimensional variations of CSEB due to drying shrinkage are countered with the cement addition. An optimum amount of (6%) for both types of cement can be recommended for successful blocks performing without notable dimensional instability.

The cyclic exposure to humidity and temperature does not weaken the mechanical performance of CSEB despite the scaling phenomena observed at the end of the test. This is due to the continuous reactions of cement hydration that are favoured under such ambient conditions, and which still take place in the long term. The CEM II shows a particular efficiency with regard to that wet-dry test.

Sulphates affect the mechanical behaviour of CSEB. The compressive strength is weakened after the cyclic exposure involving sulphates, humidity and temperature compared to the cyclic exposure involving water and temperature. However, the use of CEM I resistant to sulphates at high percentage can make the blocks withstanding the action of sulphates.

Sulphates can nevertheless fill the air pores under the effect of temperature through crystallization of products issued from their reactions with cement. This can lead to less material loss contrary to water exposure that likely causes leaching of soluble products.

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References

[1] K.K.G.K.D. Kariyawasam and C. Jayasinghe, *Cement Stabilized Rammed Earth As A Sustainable Construction Material*. Construction and Building Materials. 105 (2016), pp. 519-527.

[2] M. Saidi, A.S. Cherif, B. Zeghmati, and E. Sediki, *Stabilization Effects on The Thermal Conductivity and Sorption Behaviour of Earth Bricks*. Construction and Building Materials. 167 (2018), pp. 566-577.

[3] K.A. Heathcote, *Durability of earthwall buildings*, Construction and Building Materials. 9(3) (1995), pp. 185-189.

[4] A.-G. Kerali, *Durability of compressed and cement-stabilised building blocks. A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Engineering 2001*. University of Warwick, School of Engineering. http://webcat.warwick.ac.uk/record=b1377980~S1

[5] F.O. Ogunye and H. Boussabaine, *Diagnosis of assessment methods for weatherability of stabilised compressed soil blocks*, Construction and Building Materials. 16 (2002), pp. 163-172.

[6] A. Guettala, A. Abibsi, and H. Houari, *Durability study of stabilized earth concrete under both laboratory and climatic conditions exposure*. Construction and Building materials. 20 (2006), pp. 119-27.

[7] I. Alam, A. Naseer, and A. Shah, *Economical stabilization of clay for earth buildings construction in rainy and flood prone areas*, Construction and Building Materials. 77 (2015), pp. 154-159.

[8] J. Yuan, Y. Liu, Z. Tan, and B. Zhang, *Investigating the failure process of concrete under the coupled actions between sulfate attack and drying −wetting cycles by using X-ray CT*. Construction and Building Materials. 108 (2016), pp. 129-138. https://doi.org/10.1016/j.conbuildmat.2016.01.040.

[9] S. Wild, J.M. Kinuthia, G.I. Jones, and D.D. Higgins, *Suppression of swelling associated with ettringite formation in lime stabilized bearing clay soils by partial substitution of lime with ground granulated blastfurnace slag.* Eng. Geol. 51 (1999), pp. 257-277.

[10] H. Houben and H. Guillaud, *Earth construction a comprehensive guide*. Intermediate Technology Publication (1994), London.

[11] M. Mahdad, A. Benidir, and A. Brara, *Hydro-mechanical properties and durability of earth blocks: influence of different stabilizers and compaction levels*. International Journal of Sustainable Building Technology and Urban Development. 9(2) (2018), pp.44-60. https://doi.org/10.12972/susb.20180006.

[12] P.J. Walker, *Strength, Durability and shrinkage characteristics of cement stabilised soil blocks*. Cemenf & Concrete Composites. 17 (1995), pp. 301-310. ISSN: 0958-9465

[13] J.R. González-López, CA. Juárez-Alvarado, B. Ayub-Francis, and JM. Mendoza-Rangel, *Compaction effect on the compressive strength and durability of stabilized earth blocks*. Construction and Building Materials. 163 (2018), pp.179-188.

[14] O. Izemmouren, A. Guettala, and S. Guettala, *Mechanical Properties and Durability of Lime and Natural Pozzolana Stabilized Steam-Cured Compressed Earth Block Bricks*. Geotech Geol Eng. 33 (2015), pp.1321-1333.

[15] L. Zhang, A. Gustavsen, B.P. Jelle, L. Yang, T. Gao, and Y. Wang, *Thermal conductivity of cement stabilized earth blocks*. Construction and Building Materials. 151 (2017), pp. 504-511.

[16] K. Dao, M. Ouedraogo, Y. Millogo, J.-E. Aubert, and M. Gomina, *Thermal, hydric and mechanical behaviours of adobes stabilized with cement*. Construction and Building Materials. 158 (2018), pp. 84-96.

[17] E.A. Adam and P.J. Jones, *Thermophysical properties of stabilised soil building Blocks*. Building and Environment. 30(2) (1995), pp. 245-253.

[18] A.G. Kerali, *In-service deterioration of compressed earth blocks*. Geotechnical and Geological Engineering. 23 (2005), pp. 461-468.

[19] South African National Standards SANS 1215 (2008).

[20] R.N. Yong and V.R. Ouhadi, *Experimental study on instability of bases on natural and lime/cement-stabilized clayey soils*. Applied Clay Science. 35 (2007), pp. 238-249.

[21] M.G. Lunt, *Stabilized soil blocks for building construction*. Overseas Building Notes. (1980), p. 184.

[22] CNERIB. *Recommandations pour la production et mise en œuvre du béton de terre stabilisée*, CNERIB, Algiers, Algeria 1993, p.33.

[23] S. George, D. Ponniah, and J. Little, *Effect of temperature on lime −soil stabilization*, Construction and Building Materials. 6(4) 1992, pp. 247-252.

[24] S.M. Rao and P. Shivananda, *Role of curing temperature in progress of lime −soil reactions*, Geotech. Geol. Eng. 23(1) (2005), pp.79-85.

[25] M. Ben Mansour, A. Jelidi, A.S. Cherif, and S. Ben Jabrallah, *Optimizing thermal and mechanical performance of compressed earth blocks (CEB)*. Construction and Building Materials. 104 (2016), pp. 44-51.

[26] I. Goual, M.S. Goual, and A. Ferhat, *Stabilisation aux liants hydrauliques des tufs de la région de Laghouat : l'influence des conditions de durcissement à l'air libre et à l'eau sur le comportement mécanique*, CMEDIMAT (2005).

[27] J.M. Kinuthia, S. Wild, and G.I. Jones, *Effects of monovalent and divalent metal sulphates on consistency and compaction of lime-stabilised kaolinite*. Applied Clay Science. 14 (1999), pp. 27-45.